Journal of Forestry Research (2012) 23(3): 481-490
DOI 10.1007/s11676-012-0288-7

ORIGINAL PAPER

Bending moment resistance of corner joints constructed with spline under diagonal tension and compression

Sadegh Maleki • Akbar Rostampsour Haftkhani • Mosayeb Dalvand
Mehdi Faezipour • Mehdi Tajvidi

Received: 2011-09-10; Accepted: 2011-12-20

Abstract: We determined the effects of the penetration depth and spline material and composite material type as well as joining method on bending moment resistance under diagonal compression and tension in common wood panel structures. Composite materials were laminated medium density fiberboard (MDF) and particleboard. Joining methods were butt and miter types. Spline materials were high density fiberboard (HDF). The penetration depths of plywood, wood (*Carpinus betolus*) and spline were 8, 11 and 14 mm. The results showed that in both diagonal compression and tension, MDF joints are stronger than particleboard joints, and the bending moment resistance under compression is higher compared with that in tension. The highest bending moment resistance under tension was shown in MDF, butt joined using plywood spline with 8 mm penetration depth, whereas under compression bending moment resistance was seen in MDF, miter joined with the HDF spline of 14 mm penetration depth.

Keywords: Penetration depth; composite material type; joining type; bending moment resistance

Introduction

Numerous opinions were focused on the importance of joints in manufacturing furniture. Eckelman (2003) stated that joints are generally the weakest part of a piece of furniture and they are the primary failure cause. Ho (1991) indicated that the strength and the stiffness of joints would normally determine the strength and rigidity of the furniture.

The online version is available at http://www.springerlink.com

Sadegh Maleki (✉) • Akbar Rostampsour Haftkhani
Mosayeb Dalvand • Mehdi Faezipour • Mehdi Tajvidi
Department of Wood and Paper Science and Technology, College of Natural Resources, University of Tehran, Karaj 31587–77878, Iran
E-mail: S.maleki3@gmail.com

Responsible editor: Yu Lei

Butt and miter joining methods are commonly used for making corner joints in cabinets, bookcases and shelves with wood or wood–based panels. These types of joining are often reinforced by spline, dowel and biscuit together with adhesives. Spline is commonly made from thin strips of wood, HDF or plywood.

Corner joints of the case-type furniture will be subject to different types of loads during their usages such as compression, tension, vertical shear and racking (bending moment). Among the mentioned loads, racking (Fig. 1) is the most destructive one (Jones and Lutes 1993).

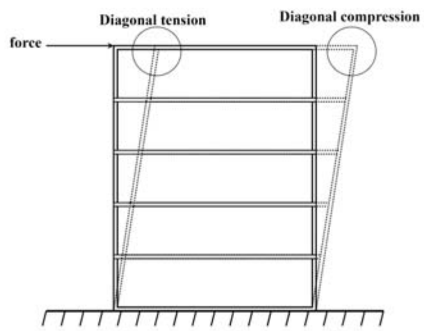

Fig. 1 Mechanical forces for corner joints of the case furniture

Several studies were carried out on bending moment resistance of case type corner joints fabricated with dowel as a common fastener. Zhang and Eckelman (1993) studied the bending moment resistance of single-dowel corner joints made with particleboard in case construction. The results showed that bending moment resistance of the single dowel corner joints increased significantly either when dowel diameter was increased from 6.4 mm to 19 mm or the depth of the dowel embedment in the face member was increased from 6.4 mm to 15.9 mm. However, the changes in depth of embedment in the edge member from 19 mm to 38 mm had no effect on bending moment resistance.

Zhang and Eckelman (1993) studied the rational design of multi–dowel corner joints in case construction. The results

showed that maximum strength per dowel was obtained when dowels were spaced at least 76 mm apart. The results also indicated that the joints exhibit different behaviors when loaded diagonally in tension and compression. And the strength of joints loaded in compression was presumably related to the internal bond strength of the board, whereas, that of joints loaded in tension was likely to be related to the surface tensile strength.

Tankut (2005) indicated that maximum moment capacity per dowel was obtained in joints when the spacing between dowels was at least 96 mm. He also stated that the spacings of 32 mm and 64 mm resulted in a reduction of maximum load-bearing capacity per dowel due to overlapping zones of influence by neighboring dowels.

Several studies showed the effects of main factors such as adhesive type, panel type and types of fastener such as screw, biscuit and spline.

Tankut and Tankut (2010) studied the effects of the edge banding material (namely polyvinyl chloride (PVC), melamine and wood veneer), thickness of edge banding material (0.4, 1 and 2 mm), and wood composite panel type (laminated MDF and particleboard) on the diagonal tension and compression strength of corner joints in case-type furniture. They clearly indicated that the diagonal tensile strength was greater than the diagonal compressive strength. In all L-type corner joints, samples with edge banding showed higher diagonal tensile and compressive strengths than those in control samples, and laminated MDF corner joints were stronger than laminated particleboard ones. From edge banding type, melamin-type edge banding material showed higher diagonal tensile and compressive strengths than others, whereas the lowest values were shown in PVC edge banding.

Tankut and Tankut (2009) studied the effects of fastener (spline joint, butt joints, biscuit joints, plain dowel joints and grooved dowel joints), glue (polyvinyl acetate D3, polyvinyl acetate D4 and Desmodur VTKA), and composite material types (laminated MDF and particleboard) on the strength of corner joints in case-type furniture construction. They indicated that the diagonal tensile strength is greater than compressive strength in all joints, the melamine-coated fiberboard corner joints are stronger than the melamine-coated particleboard corner joints, and the diagonal tensile and compressive strengths of the joints glued with polyvinyl acetate D4 adhesive were higher than similar joints glued with polyvinyl acetate D3 and Desmodur VTKA adhesives.

Kasal et al. (2006) studied the bending strength of screwed corner joints made with different materials. The results indicated that the joints connected with glue were better than those without glue, and the strength of cases with fiberboard was better than those with particleboard. Atar et al. (2009) studied diagonal compression and tension performances for case furniture corner joints constructed with wood biscuits. They evidently indicated that the highest diagonal compressive and tensile strengths were obtained in melamine-coated fiberboard with Desmodur VTKA adhesive. They recommended that the wood biscuits from solid woods can be used in the corner joints of the case-type furniture.

Some studies were conducted on the bending moment resistance of case-type corner joints constructed with spline. Tankut and Tankut (2010) advised that spline joint with 0.4 mm melamine edge banding was the most robust corner joint type for case furniture made with laminated MDF panels. They also showed that case furniture corner joints constructed with spline had bigger bending moment resistances to those made with biscuit, plain and grooved dowel. Eckelman and Lin (1997) studied the bending moment of corner joints constructed with injection molded splines. The results showed that high-strength joints can be formed with injection molded splines, but the strength of the joints was highly dependent on the configuration of the spline. Furthermore, the strength of the joints was compared with the expected strength of similar joints constructed with screws and dowels.

The main factors affecting the bending moment resistance of corner joints constructed with spline are composite panel type, joining type, penetration depth, material type of spline and adhesive type (Tankut and Tankut 2009; Eckelman and Lin 1997). A relatively easy way to strengthen corner joint is to add a spline across the joint. The spline serves to reinforce the joint and keep two sections aligning with each other. Since spline can be used to reinforce butted and mitered corner joints in case and box-type furniture made with wood and wood-based panels. Therefore, our study aimed at determining the effects of the composite panel type, joining type, penetration depth and material type of spline on the bending moment resistance under diagonal compression and tension in L-type corner joints. Other factors such as preparation method, adhesive properties, lamination, and specimens' mass were kept constant.

Materials and methods

The materials were laminated MDF and laminated particleboard with a thickness of 16 mm for making the joint members, and also high density fiberboard (HDF), plywood (3-ply) and solid wood (*Carpinus betolus*) with a nominal thickness of 3 mm for making the splines. All materials were prepared from local companies in Iran.

Density and moisture contents were measured according to EN 323 and EN 322, respectively, for panels and ASTM D 2395 for wood.

The internal bonding strength and MOE of the laminated MDF and laminated particleboard were measured according to EN 319 and EN 310, respectively. The main characteristics of the panels and splines are shown in Table 1.

Table 1.Main characteristics of the panels

Panel type	Density ($g\cdot cm^{-3}$)	MOR (MPa)	MOE (MPa)	IB (MPa)
Laminated MDF	0.62	21.3	3574	0.55
Laminated particleboard	0.64	17.0	3641	0.80
High density fiberboard	0.79	---	---	---
Plywood	0.55	---	---	---
Hornbeam wood	0.65	---	---	---

The adhesive was polyvinyl acetate (PVA) (pH = 5, solid content = 60 % and density = 1.08 g· cm^{-3}).

The panels were cut into pieces (160 mm × 230 mm × 16 mm) to prepare the mitered specimens for test. Thereafter, the pieces of panels were mitered in one corner. The mitered corner was grooved for inserting the spline. For the butted specimes, the panels were cut to pieces (160 mm × 230 mm × 16 mm) for face member and (144 mm × 230 mm × 16 mm) for butt member. One corner of each piece was grooved for inserting the spline. These two types of configuration are shown in Fig. 2.

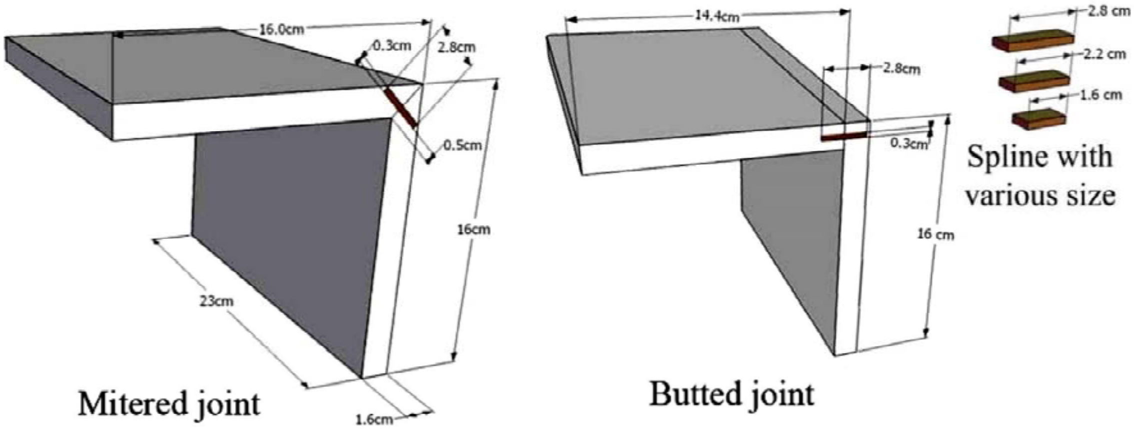

Fig. 2 The configuration of test specimens and spline with various widths.

The size of the spline was 230 mm × 3 mm in length and thickness, respectively, with different widths including 16, 22 and 28 mm, as half of each spline penetrated into the groove. The splines were made from three materials namely HDF, plywood and wood (*Carpinus Betulus*). The HDF splines were in machine direction, plywood splines were parallel to grain and wooden splines were in perpendicular to grain direction. The width and thickness of groove for inserting the spline were 1 mm more than those of spline.

The cut panels and splines were placed in a conditioning chamber with a relative humidity of (65±1)% and a temperature of (20±2)°C until reaching a constant weight

For preparing the test specimens, the spline and groove as well as mitered and butted surfaces were glued, and then, the spline was inserted into the groove. The joints were fastened together by using a C clamp and were left to harden.

The specimens were left for at least 2 weeks to allow curing the glue. Then, they were stored again in the conditioning chamber until reaching a constant weight.

A total of 288 specimens were constructed and tested [2 loading types (diagonal compression and tension) × 2 panel types (MDF and particleboard) × 2 joining types (miter and butt) × 3 spline material types (HDF, plywood and wood (*Carpinus betulus*) × 3 spilne penetration depths (8, 11 and 14 mm) × 4 (replicates for each treatment)].

A computer-controlled INSTRON machine (model 4486) was used to apply the diagonal compression and tension. Loading methods on the joints in diagonal compression and tension were illustrated in Fig. 3. The loading rate was 5 mm· min^{-1}. Loading continued until the specimens failed. Subsequently, the maximum load for each specimen was registered for calculating the bending moment resistance in diagonal tension and compression with following equations:

$$M_c = P_{\max} \times y_c \tag{1}$$

$$M_t = 0.5P_{\max} \times y_t \tag{2}$$

where, M_c is bending moment resistance of joint under compression loading (N· m), M_t is bending moment resistance of joint under tension loading (N· m), $P_{\max}$ is the maximum load in each tested specimen (N), y_c is moment arm in compression (m) and y_t is moment arm in tension (m).

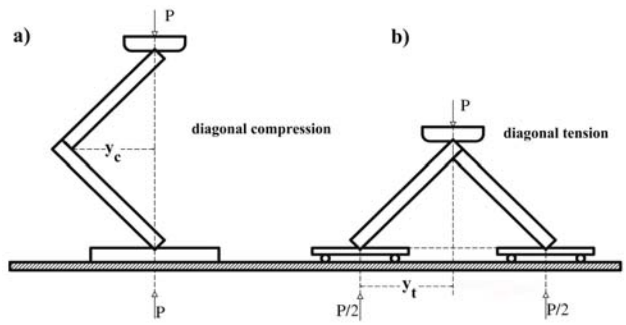

Fig. 3 Methods of loading on the joints in diagonal compression (a) and tension (b).

The collected data were statistically normalized and then were analyzed by SPSS Software. The multiple variance analysis determined the differences among the factors [(panel types) × (joining types) × (loading types) × (spline material types) × (spilne penetration depths)]. The Duncan test was used for determining the significant differences among the groups. All comparisons were made at a confidence level of 95%. Four replicates for each treatment were tested.

Result and discussion

The averages and standard deviations of the bending moment under diagonal compression and tension according to panel types, joining types, spline material types and spline penetration depths are shown in Table 2. The multivariate analyses of variance for bending moment resistance under diagonal tension and compression are given in Tables 3 and 4, respectively. The spline material types in tension, and panel and joining types in compression did not have significant effects on bending moment resistance.

The results indicated that the joints exhibit different behavior under diagonal tension and compression, and the bending moments of the all joints under diagonal compression were higher than those under diagonal tension. The reason for this observation was presented by Zhang and Eckelman (1993). They stated that the bending moment resistance of joints loaded in compression was presumably related to the internal bond strength of the board, whereas that of joints loaded in tension was likely to be related to the surface tensile strength parallel to the plane of the board.

Table 2. Averages and standard deviations of the bending moment resistance values (N· m) in diagonal tension and compression according to panel types, joining types, spline material types and spline penetration depths.

Composite material	Spline material	Spline penetration depth (spline width) (mm)	Compression		Tension	
			butt	miter	butt	miter
MDF	HDF	8 (16)*	30.98 (3.0)**	68.07 (9.5)	37.42 (1.9)	26.81 (6.8)
		11 (22)	42.46 (3.2)	66.53 (9.0)	38.75 (3.8)	26.28 (4.3)
		14 (28)	37.17 (6.6)	51.00 (0.7)	32.54 (10.3)	25.37 (3.3)
	plywood	8 (16)	36.97 (2.4)	41.15 (6.9)	39.46 (4.8)	26.25 (1.5)
		11 (22)	51.61 (5.7)	51.42 (6.9)	40.26 (3.0)	18.32 (2.7)
		14 (28)	55.40 (2.7)	50.07 (3.3)	42.54 (3.0)	16.23 (1.6)
	wood	8 (16)	36.88 (5.1)	35.56 (1.8)	38.23 (7.3)	30.78 (1.2)
		11 (22)	53.10 (3.7)	30.11 (6.0)	40.67 (1.7)	28.38 (1.3)
		14 (28)	49.20 (1.7)	46.06 (7.7)	36.81 (3.6)	35.50 (2.2)
Particleboard	HDF	8 (16)	45.08 (3.2)	55.49 (3.6)	22.98 (2.8)	24.76 (2.9)
		11 (22)	49.01 (2.3)	53.09 (4.0)	29.79 (4.1)	27.70 (3.2)
		14 (28)	45.74 (11.9)	45.02 (3.1)	23.59 (2.9)	28.58 (1.8)
	plywood	8 (16)	44.82 (5.3)	35.20 (2.2)	32.02 (5.3)	28.43 (6.2)
		11 (22)	56.12 (4.5)	42.97 (4.4)	33.25 (2.2)	25.27 (2.8)
		14 (28)	62.39 (7.8)	38.33 (5.8)	34.98 (3.3)	13.65 (1.5)
	wood	8 (16)	39.54 (4.2)	35.00 (3.5)	34.47 (2.0)	38.73 (0.3)
		11 (22)	49.08 (5.8)	30.11 (6.0)	34.47 (1.6)	34.66 (2.5)
		14 (28)	53.94 (3.8)	46.06 (7.7)	37.63 (5.4)	39.29 (3.8)

* The value in the parenthesis is the spline width, as the half of each spline penetrates into the groove made in one corner of the joint member. ** The value in the parenthesis is standard deviation.

Table 3. Analysis of variance results for bending moment in diagonal tension

Source	Degrees of freedom	Mean Square	F	Sig.
Board type	1	145.28	9.68	0.002
Joining type	1	2001.57	133.38	0.000
Jointer type	2	736.77	49.10	0.000
Spline penetration depth	2	17.39	1.16	0.318
Board type * Joining type	1	904.84	60.30	0.000
Board type * Jointer type	2	125.22	8.34	0.000
Board type * Spline penetration depth	2	8.41	0.56	0.573
Joining type * Jointer type	2	615.76	41.03	0.000
Joining type * Spline penetration depth	2	68.13	4.54	0.013
Jointer type * Spline penetration depth	4	73.22	4.88	0.001
Board type * Joining type * Jointer type	2	5.68	0.38	0.686
Board type * Joining type * Spline penetration depth	2	26.31	1.75	0.178
Board type * Jointer type * Spline penetration depth	4	27.99	1.87	0.122
Joining type * Jointer type * Spline penetration depth	4	124.71	8.31	0.000
Board type * Joining type * Jointer type * Spline penetration depth	4	11.46	0.76	0.551
Error	107	15.01		
Total	143			

Table 4. Analysis of variance results for bending moment in diagonal compression

Source	Degrees of freedom	Mean Square	F	Sig.
Board type	1	4.81	0.16	0.689
Joining type	1	35.69	1.20	0.276
Jointer type	2	615.97	20.66	0.000
Spline penetration depth	2	579.76	19.44	0.000
Board type * Joining type	1	1312.11	44.01	0.000
Board type * Jointer type	2	7.39	0.25	0.781
Board type * Spline penetration depth	2	38.57	1.29	0.279
Joining type * Jointer type	2	2185.30	73.29	0.000
Joining type * Spline penetration depth	2	432.77	14.51	0.000
Jointer type * Spline penetration depth	4	474.16	15.90	0.000
Boardtype * Joining type * Jointer type	2	279.31	9.37	0.000
Board type * Joining type * Spline penetration depth	2	17.74	0.59	0.553
Board type * Jointer type * Spline penetration depth	4	9.72	0.33	0.860
Joining type * Jointer type * Spline penetration depth	4	182.02	6.10	0.000
Board type * Joining type * Jointer type * Spline penetration depth	4	24.14	0.81	0.522
Error	104	29.82		
Total	140			

The results demonstrated that the bending moment resistance of butted joints made with MDF is higher than those of mitered joints made with particleboard.

The highest bending moment resistance in diagonal tension was seen in MDF panel, butted joint and plywood spline with penetration depth of 14 mm, whereas, the lowest was observed in particleboard panel, mitered joint and plywood spline with penetration depth of 14 mm. Moreover, the highest bending moment resistance under diagonal compression was seen in MDF panel with mitered joint, HDF spline with penetration depth of 8 mm, while the lowest was seen in particleboard panel, mitered joint and wooden spline with 11 mm penetration depth.

Performance of joints in diagonal tension

On the basis of panel types, jointing types, spline material types and spline penetration depths, the average values of bending moment resistance under diagonal tension are shown in Table 5. Butted joint made with MDF member and wooden spline with penetration depth of 8 mm had the highest bending moment resistance under diagonal tension. The bending moment resistance of corner joints constructed with spline under diagonal tension is likely to be a function of mechanical properties of the spline and the panel, surface bonding strength of spline into the groove made for inserting the spline, and the modes of failure under load. The groove made into MDF for inserting the spline has a smooth surface in comparison to the particleboard. This is the reason that the joints made with MDF panels had a higher bending moment resistance than those made with particleboard panels under diagonal tension. These results are similar to the findings of Tankut and Tankut (2009), Tankut and Tankut (2010), and Atar et al. (2010). The butted joints resisted better than mitered joints against diagonal tension.

Table 5. Bending moment values (N· m) of joints in diagonal tension according to the panel types, joining types, spline material types and spline penetration depths

		Bending moment (N.m)	Std.*	HG**
Panel type	MDF	32.25	8.54	
	Particleboard	30.12	7.06	
Joining type	Butt	34.99	6.54	
	Miter	27.34	7.27	
Jointer type	HDF	28.71	6.39	A
	Plywood	29.22	9.79	A
	Wood	35.74	4.56	B
Spline penetration depth (mm)	8	31.54	6.80	A
	11	31.48	7.02	A
	14	30.56	9.63	A

* Standard deviation; ** HG: homogeneity group (HG) different letters in a column refer to significant differences among the factors at 0.05 confidence level.

Moreover, the results also demonstrated that joints made with wooden spline and less spline penetration depth resisted better against diagonal tension. The main reason for this is presumably related to the surface bonding strength between the spline and the groove, and modes of failure. The surface bonding strength between the panel and wooden spline is higher than those between the surface of panel and spline made with plywood or HDF. The main reason for the high bending moment resistance of wooden spline in comparison to plywood spline is the delaminataion of plywood spline under tension load. The mode of failure changes with the increase of penetration depth. The failures in joints constructed with less spline penetration depth occur in the panel, but those in joints constructed with high spline penetration depth

occur in the spline. Since the panel resists better than the spline against diagonal tension, bending moment resistance of joints with less spline penetration depth under diagonal tension is higher than that of joints with high spline penetration depth. It is worth noting that the failure occurred in the panel is in the face member. Moreover, the bending strength of spline and the net section area for tolerating the load decreases with the increase of spline penetration depth. This is why the bending moment resistance of joints under diagonal tension decreases with the increase of spline penetration depth. This was confirmed by Zhang and Eckelman (1993). They indicated that the main factor influencing the strength of joints loaded in compression is internal bond strength of the board, whereas in tension it is the surface tensile strength of the panel.

Under diagonal tension, changing the panel type, joining type and spline material type led to 7%, 28% and 24% change in the bending moment resistance, respectively. Changing the spline penetration depth from 8 mm to 14 mm led to 3% decrease in the bending moment resistance. Some failure modes of joints under diagonal tension are shown in Fig. 4.

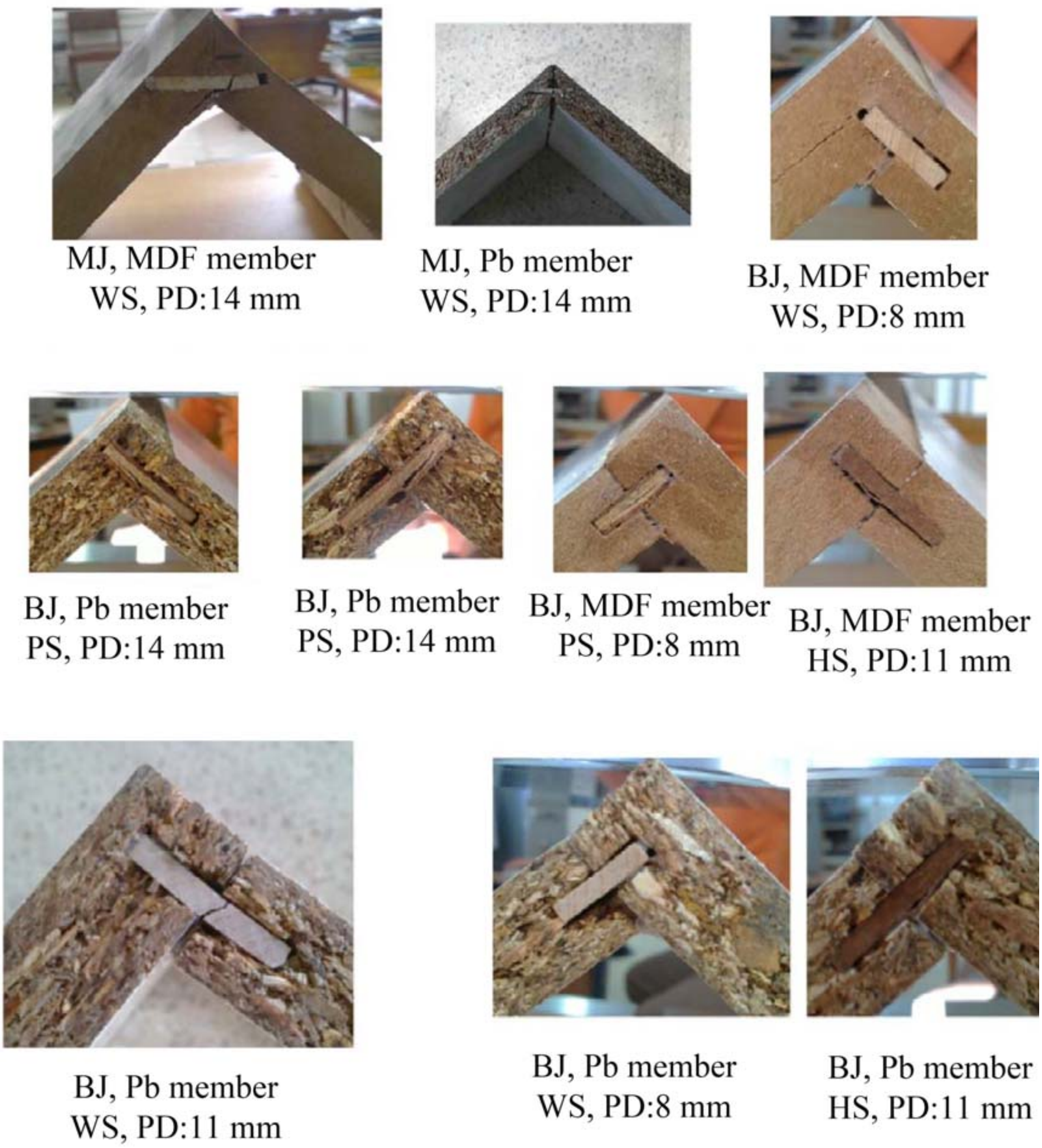

Fig. 4 Some failure modes of joints under diagonal tension. MJ: mitered joint; BJ: butted joint; WS: wooden spline; PS: plywood spline; HS: HDF spline; PD: spline penetration depth; Pb: particleboard.

Interactions between two factors are shown in Table 6. The highest change in the bending moment under diagonal tension was seen in the interaction of joining types and spline materials (73.6%), whereas the lowest change was seen in the interaction of panel types and spline penetration depths (11.9%).

Table 6. Bending moment values of interactions between two factors in diagonal tension.

		Bending moment (N· m)	Std.	HG
panel type, joining type				
MDF	Butt	38.52	5.25	C
	Miter	25.99	6.29	A
Particleboard	Butt	31.46	5.79	B
	Miter	28.73	8.02	AB
panel type, jointer type				
MDF	HDF	31.19	7.52	BC
	Plywood	30.51	11.27	AB
	wood	35.06	5.38	CD
Particleboard	HDF	26.23	3.76	A
	Plywood	27.93	8.08	AB
	wood	36.45	3.49	D
panel type, spline penetration depth (mm)				
MDF	8	33.16	6.92	A
	11	32.11	8.96	A
	14	31.50	9.77	A
Particleboard	8	29.86	6.40	A
	11	30.86	4.41	A
	14	29.62	9.60	A
joining type, jointer type				
Butt	HDF	30.84	7.72	C
	Plywood	37.08	5.16	D
	wood	37.05	4.33	D
Miter	HDF	26.58	3.80	B
	Plywood	21.36	6.32	A
	wood	34.38	4.48	D
joining type, spline penetration depth (mm)				
Butt	8	34.10	6.92	B
	11	36.20	4.83	B
	14	34.68	7.64	B
Miter	8	28.88	5.68	A
	11	26.77	5.57	A
	14	26.44	9.78	A
jointer type, spline penetration depth (mm)				
HDF	8	27.99	6.84	A
	11	30.63	6.09	ABC
	14	27.52	6.18	A
Plywood	8	31.54	6.72	ABC
	11	29.28	8.86	AB
	14	26.85	12.84	A
Wood	8	35.34	4.87	CD
	11	34.55	4.78	BCD
	14	37.31	3.80	D

Interactions among all factors are shown in Table 7. The highest change of the bending moment under diagonal tension was seen in the interactions of joining types, material types and penetration depths of the spline (159%), while the lowest change corresponded to the interactions of the panel types, material types and penetration depths of the spline (61%).

Table 7. Bending moment values of interactions among all factors in diagonal tension.

			Bending moment (N· m)	Std.	HG
panel type, joining type, jointer type					
MDF	butt	HDF	36.23	6.47	EF
		Plywood	40.75	3.59	G
		Wood	38.57	4.68	FG
	miter	HDF	26.15	4.59	BC
		Plywood	20.27	4.86	A
		Wood	31.55	3.43	D
Particleboard	butt	HDF	25.45	4.42	BC
		Plywood	33.42	3.67	DE
		Wood	35.52	3.49	EF
	miter	HDF	27.02	2.95	C
		Plywood	22.45	7.57	AB
		Wood	37.46	3.34	EFG
panel type, joining type, spline penetration depth (mm)					
MDF	butt	8	38.37	4.76	D
		11	39.89	2.81	D
		14	37.29	7.32	CD
	miter	8	27.94	4.26	AB
		11	24.33	5.29	A
		14	25.70	8.52	A
Particleboard	butt	8	29.82	6.13	AB
		11	32.50	3.32	BC
		14	32.06	7.33	BC
	miter	8	29.91	6.99	AB
		11	29.21	4.88	AB
		14	27.17	11.23	AB
panel type, jointer type, spline penetration depth (mm)					
MDF	HDF	8	32.11	7.32	ABCDE
		11	32.51	7.65	BCDE
		14	28.95	8.06	ABCD
	Plywood	8	32.85	7.78	BCDE
		11	29.29	12.02	ABCD
		14	29.39	14.24	ABCD
	Wood	8	34.50	6.30	CDE
		11	34.53	6.71	CDE
		14	36.15	2.89	DE
Particleboard	HDF	8	23.87	2.81	A
		11	28.75	3.59	ABCD
		14	26.09	3.47	ABC
	Plywood	8	30.23	5.67	ABCDE
		11	29.26	4.86	ABCD
		14	24.31	11.64	AB
	Wood	8	36.30	2.68	DE
		11	34.57	1.95	CDE
		14	38.46	4.42	E
joining type, jointer type, spline penetration depth (mm)					
Butt	HDF	8	30.20	8.04	CDE
		11	34.27	6.04	EFG
		14	28.06	8.50	CD
	Plywood	8	35.74	6.13	EFG
		11	36.76	4.46	FG
		14	38.76	4.99	G

Continued Table 7

			Bending moment (N· m)	Std.	HG
	Wood	8	36.35	5.37	FG
		11	37.57	3.66	G
		14	37.22	4.29	FG
Miter	HDF	8	25.79	4.96	BC
		11	26.99	3.57	BCD
		14	26.98	2.98	BCD
	Plywood	8	27.34	4.34	CD
		11	21.79	4.51	B
		14	14.94	1.99	A
	Wood	8	34.19	4.35	EFG
		11	31.52	3.82	DEF
		14	37.40	3.53	G

Performance of joints in diagonal compression

The average values of bending moment resistance under diagonal compression according to panel types, joining types, jointer types and spline penetration depths are shown in Table 8. Butted joints made with MDF member and HDF spline with penetration depth of 14 mm had the highest bending moment resistance under diagonal compression.

Table 8. Bending moment values (N· m) of joints in diagonal compression according to the panel types, joining types, spline material types and spline penetration depths.

		Bending moment (N· m)	Std.*	HG**
Panel type	MDF	46.24	11.72	
	Particleboard	46.07	9.55	
Joining type	butt	46.53	9.29	
	Miter	45.78	11.95	
Jointer type	HDF	49.22	11.79	B
	Plywood	47.11	9.50	B
	Wood	42.05	9.46	A
Spline penetration depth (mm)	8	42.21	10.96	A
	11	47.86	11.26	B
	14	48.44	8.70	B

* Standard deviation; ** HG: homogeneity group (HG) different letters in a column refer to significant differences among the factors at 0.05 confidence level.

The bending moment resistance of spline into panel under diagonal compression is likely to be a function of bending strength of spline, internal bond strength of panel and modes of failure. When the joint is diagonally loaded in compression, either the spline or the panel fails. Some failure modes of joints under diagonal compression are shown in Fig. 5. The failure of the panel in butted joints usually occurred along the thickness of the face member and at the end of the place where the spline penetrated into the groove. As illustrated in Table 8, the bending moment resistance partially increased with the increase of spline penetration depth. The reason for this in butted joints is likely the increase of the internal bond strength of failure lines along with the increase of spline penetration depth. When the penetration depth is 8 mm, the groove is placed in the middle thickness of the panel that has the lowest internal bond strength. The internal bond strength increases when the spline penetrates close to the surface of the panel. Moreover, with the increase of spline penetration depth, the bending strength of spline and the net section area for tolerating the loads decrease. As shown in Fig. 5, the failure line in butted joint is close to the surface of the face member when the spline penetration depth is increased.

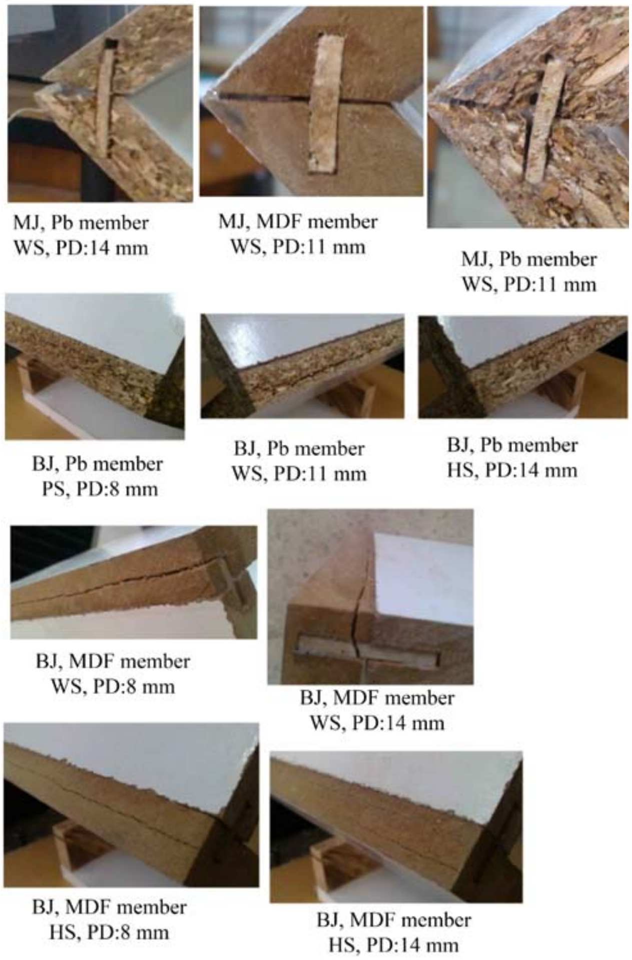

Fig. 5 Some failure modes of joints under diagonal compression. MJ: mitered joint; BJ: butted joint; WS: wooden spline; PS: plywood spline; HS: HDF spline; PD: spline penetration depth; Pb: particleboard.

The failure in mitered joints under diagonal compression usually occurred in the spline. The increase in spline penetration depth in mitered joint did not have a significant effect on bending moment resistance under diagonal compression, and the main factor here is the spline material type, as demonstrated in Table 9.

Table 9. Bending moment values of interactions between two factors in diagonal compression.

		Bending moment (N· m)	Std.	HG
panel type, joining type				
MDF	Butt	43.53	9.10	A
	Miter	48.88	13.40	B
Particleboard	Butt	49.54	8.58	B
	Miter	42.50	9.29	A
panel type, jointer type				
MDF	HDF	49.37	15.36	B
	Plywood	47.60	8.03	AB
	wood	41.82	9.38	A
Particleboard	HDF	49.08	6.62	B
	Plywood	46.64	10.88	AB
	wood	42.31	9.75	A
panel type, spline penetration depth (mm)				
MDF	8	41.60	13.38	A
	11	49.10	12.73	B
	14	48.15	7.03	AB
Particleboard	8	42.85	7.94	AB
	11	46.63	9.70	AB
	14	48.73	10.32	B
joining type, jointer type				
Butt	HDF	41.74	8.14	AB
	Plywood	51.20	9.71	C
	wood	46.86	7.68	BC
Miter	HDF	57.03	9.81	D
	Plywood	43.19	7.58	B
	wood	37.24	8.69	A
joining type, spline penetration depth (mm)				
Butt	8	39.05	6.15	A
	11	50.22	5.82	B
	14	50.64	10.05	B
Miter	8	45.52	13.76	B
	11	45.70	14.39	B
	14	46.14	6.46	B
jointer type, spline penetration depth (mm)				
HDF	8	49.90	14.92	CD
	11	52.77	10.25	D
	14	44.71	8.29	BC
Plywood	8	39.54	5.69	AB
	11	50.46	7.00	CD
	14	51.55	10.25	CD
Wood	8	36.86	3.88	A
	11	40.03	12.07	AB
	14	48.81	6.20	CD

The butted joints with MDF resist marginally better than mitered joints with particleboard against diagonal compression. Under diagonal tension, changing the panel type, joining type and spline material type led to 0.3%, 2% and 17% change in the bending moment resistance, respectively. Changing the spline penetration depth from 8 mm to 14 mm led to 14% increase in the bending moment resistance.

Interactions between two factors are shown in Table 9. The highest change in bending moment resistance under diagonal compression was seen in the interactions of joining types and spline materials (53%), whereas the lowest change was seen in the interactions of panel types and joining types (16.5%).

Interactions among all factors are shown in Table 10. The highest change in the bending moment resistance under diagonal compression was seen in the interactions of joining types, materials and penetration depths of spline (105%), while the lowest change was seen in the interactions of panel types, joining types and spline penetration depths (50.4%).

Table 10. Bending moment values of interactions among all factors in diagonal compression.

			Bending Moment (N· m)	Std.	HG
panel type, joining type, jointer type					
MDF	butt	HDF	36.87	6.40	A
		Plywood	47.66	9.20	BC
		Wood	46.39	7.99	B
	miter	HDF	61.86	10.56	D
		Plywood	47.54	7.20	BC
		Wood	37.24	8.64	A
Particleboard	butt	HDF	46.61	6.78	B
		Plywood	54.45	9.36	C
		Wood	47.38	7.68	BC
	miter	HDF	51.76	5.53	BC
		Plywood	38.84	5.18	A
		Wood	37.24	9.17	A
panel type, joining type, spline penetration depth (mm)					
MDF	butt	8	34.94	4.44	A
		11	48.82	6.28	BCD
		14	47.25	8.77	BCD
	miter	8	48.26	16.07	BCD
		11	49.35	16.98	BCD
		14	49.04	4.95	BCD
Particleboard	butt	8	43.15	4.74	ABC
		11	51.62	5.22	CD
		14	54.02	10.46	D
	miter	8	42.52	10.66	ABC
		11	42.06	10.76	AB
		14	42.97	6.60	ABC
panel type, jointer type, spline penetration depth (mm)					
MDF	HDF	8	49.52	20.87	CDEFG
		11	54.50	14.29	G
		14	44.08	8.56	ABCDEFG
	Plywood	8	39.06	5.29	ABCD
		11	51.50	5.90	EFG
		14	52.73	3.99	FG
	Wood	8	36.22	3.61	A
		11	41.60	13.12	ABCDEF
		14	47.63	5.45	BCDEFG
Particleboard	HDF	8	50.29	6.41	DEFG
		11	51.05	3.73	EFG
		14	45.43	8.58	ABCDEFG

Continued Table 10

			Bending moment (N· m)	Std.	HG
	Ply-wood	8	40.01	6.39	ABCDE
		11	49.55	8.14	CDEFG
		14	50.36	14.36	DEFG
	Wood	8	37.59	4.33	AB
		11	38.24	11.49	ABC
		14	50.00	7.03	DEFG
joining type, jointer type, spline penetration depth (mm)					
Butt	HDF	8	38.03	8.07	BC
		11	45.74	4.35	DE
		14	41.45	9.99	BCD
	Ply-wood	8	40.90	5.68	BCD
		11	54.19	5.17	FG
		14	58.89	6.58	GH
	Wood	8	38.21	4.55	BC
		11	51.37	4.78	EF
		14	51.57	3.71	EF
Miter	HDF	8	61.78	9.45	H
		11	59.81	9.64	GH
		14	48.43	3.69	DEF
	Ply-wood	8	38.17	5.73	BC
		11	47.19	7.00	DEF
		14	44.20	7.66	CDE
	Wood	8	35.32	2.40	AB
		11	30.11	5.52	A
		14	46.06	7.15	DE

Conclusion

The bending moment resistance of all joints under diagonal compression was approximately 47% higher than those under diagonal tension. The bending moment resistance of joints made with MDF was approximately 0.3% and 7% higher than those in particleboard under both diagonal compression and tension, respectively. The bending moment resistance of butted joints was approximately 2% and 28% higher than those of mitered joints under diagonal compression and tension, respectively.

The bending moment resistance of joints made with wooden spline under diagonal tension is higher than that with plywood and HDF spline, and those of joints made with HDF under compression were higher than plywood and wooden spline. The bending moment resistance of joints under diagonal compression increased with the increase of the spline penetration depth. However, the bending moment resistance of joints under tension decreased with the increase of the spline penetration depth.

The changes in the bending moment resistance under diagonal tension were higher than those under diagonal compression. Therefore, the joint should be reinforced against this load. This will be the best achieved by the proper selection of factors influencing bending moment resistance. Moreover, the butted joints can be reinforced with edge banding.

As a result, the spline penetration depth does not have any significant effects on bending moment resistance neither under diagonal tension nor compression. Accordingly, it is recommended that the joints can be constructed with spline into less penetration depth. This will save both adhesive and spline material consumption.

Reference

ASTM D 2395. 1999. Test methods for specific gravity of wood and wood-base materials. Philadelphia, American society for testing and materials.

Atar M, Keskin H, Peker H, Ustundag A, Togay A, Candan Z. 2010. Impacts of different joint angles and adhesives on diagonal tension performances of box-type furniture. *Bioresources*, **5**: 343–355.

Atar M, Ozcifci A, Altinok M, Celikel U. 2009. Determination of diagonal compression and tension performances for case furniture corner joints constructed with wood biscuits. *Materials & Design*, **30**(3): 665–670.

Eckelman C, Lin FC. 1997. Bending Strength of Corner Joints Constructed with Injection Molded Splines. *Forest Products Journal*, **47**(4): 89–92.

Eckelman C. 2003. Textbook of product engineering and strength design of furniture. West Lafayette, US: Purdue University Press.

EN 310. 1993. Determination of modulus of elasticity in bending and of bending strength. German version EN 310.

EN 319. 1993. Determination of tensile strength perpendicular to the plane of the board. German version EN 319.

EN 322. 1993. Wood-based panels: determination of moisture content. German version EN 322.

EN 323. 1993. Wood-based panels: determination of density. German version EN 323.

Ho CL. 1991. The use of performance tests in evaluating joint and fastener strength in case type furniture. MS thesis. West Lafayette, US: Purdue University.

Jones A, Lutes R. 1993. Handbook of joinery. New York, USA: Sterling Press.

Kasal A, Şener S, Belgin ÇM, Efe H. 2006. Bending strength of screwed corner joints with different materials, *G.Ü. Journal of Sciences*, **19**(3): 155-161.

Tankut AN, Tankut N. 2009. Investigations the effects of fastener, glue, and composite material types on the strength of corner joints in case-type furniture construction. *Materials & Design*, **30**(10): 4175-4182.

Tankut AN, Tankut N. 2010. Evaluation the effects of edge banding type and thickness on the strength of corner joints in case-type furniture. *Materials & Design*, **31**(6): 2956–2963.

Tankut AN. 2001. Design of panel and panel-on-frame bookshelves and cabinets. Ph.D. Thesis. West Lafayette, US: Purdue University.

Tankut AN. 2005. Optimum dowel spacing for corner joints in 32 mm cabinet construction. *Forest Products Journal*, **55**(12): 100–104.

Zhang JL, Eckelman CA. 1993. Rational design of multi dowel corner joints in case construction. *Forest Products Journal*, **43**: 52–58.

Zhang JL, Eckelman CA. 1993. The bending moment resistance of single-dowel corner joints in case construction. *Forest Products Journal*, **43**:19–24.